Agent and Diligent Driver Behavior on the Car-Following Part of the Micro Traffic Flow in A Situation of Vehicles Evacuation on Sidoarjo Porong Roadway

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Summary
An agent and diligent driver behaviour on the car-following part of the micro traffic flow in a situation of vehicles evacuation on Sidoarjo Porong roadway is proposed. By paying attention to the Nagel-Schreckenberg (NaSch) model of the micro traffic flow, we modify it by inserting agent drivers and diligent ones into the driving behaviour on the car-following part. Validation of the proposed model is performed by comparing the fundamental diagram from the realistic traffic and the simulation results. Based on the actual data from the traffic on Sidoarjo Porong roadway; the effect of agent drivers and diligent ones in a situation of vehicles evacuation is observed by presenting time-space diagram; the evacuation time of the vehicles evacuation is also found for unequal vehicle densities.

Key words:
Agent drivers, Diligent drivers, Fundamental diagram, Time-space diagram, Evacuation time

1. Introduction

In the micro traffic flow, car-following model has an important role. Car-following behavior influences the activities of traffic on the roadway. The smoothness of traffic activities on the roadway is determined by the speed of vehicles on the aforementioned roadway. The flexibility of vehicles speed in the sense that the vehicles can adjust the acceleration and deceleration has been considered by Kerner [10] with inserting a parameter based on the temporal variables into the car-following model. Besides, the smoothness of traffic activities is also determined by the cooperation model between the drivers and it is associated by car-following model such as presented by [11], [12], [9]. Car-following model is also very influential in creating the stability of the traffic flow such as investigated by [9-14].

There are two major methods of car-following models, continuous models and discrete ones. Several kinds of the continuous models have been created, those are Optimal Velocity Model (OVM), Generalized Force Model (GFM), Full Velocity Difference Model (FVDM), and Two Velocity Difference Model (TVDM) in which explained in [6]; [7]; [8]; and [9], respectively. The discrete model of car-following has been developed by using Cellular Automata (CA) and it has been called by Traffic Cellular Automata (TCA) [3]. One of TCA models is proposed by Nagel and Schreckenberg [2]. It is able to reproduce several characteristics of real-life traffic flows, e.g., the spontaneous emergence of traffic jams. Their model has been called the Nagel-Schreckenberg TCA. Hereinafter, the Nagel-Schreckenberg TCA is referred as the NaSch. Maerivoet et al. [3] also state that the NaSch model has been called as a minimal model, in the sense that all the rules are a necessity for mimicking the basic features of real-life traffic flows.

Referring to the NaSch model of the micro traffic flow, in the case of evacuation, we have proposed the modified car-following model [4]. We have inserted a parameter into the driving behaviour on the car-following part, it is the agent drivers. An agent driver has a good response to the surrounding environment and also recognizes speed changes so that allowing traffic to be controlled by the best way to minimize the evacuation time. He has capability to lead the other cars and he also has information that can be derived from the evacuation control centre and transferred to the other drivers through wireless network connection. Besides, an agent driver can lead the other cars to the safe area in a fastest way. The micro traffic flow system has been reflected to the Sidoarjo Porong roadway. The location of this road is in Sidoarjo, East Java, Indonesia. The structure of Sidoarjo Porong roadway and surrounding areas are shown in Fig. 1. The road is very close with the hot mudflow disaster area and as a main artery road connects between Surabaya, the capital city of the province and the cities inside the province. The mud volcano remains have high flow rates until now [15]. The evacuation time of the vehicles evacuation has been obtained by assumption that the dike of hot mudflow is damaged and the mud overflows from the damaged dike to the nearby road spontaneously. We have observed the effect of the agent drivers with respect to the evacuation time. To improve the results of the evacuation time, we

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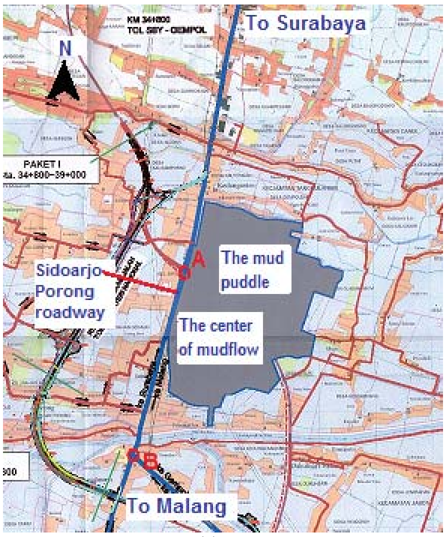
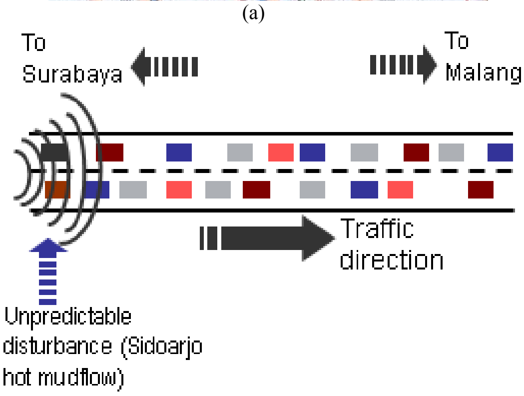
have proposed a new parameter in [1], [5] and added into the previous model [4], it is the diligent drivers. A diligent driver can expand his chance to increase the speed or maintain it. Besides, he also finds out more information on the surrounding circumstances. The difference between the agent drivers and the diligent ones is the speed of vehicles they own and the agent drivers have the other characteristics mentioned above. The evacuation time have been obtained by [4], [1], and [5] based on the simulation results without the actual data. It is better to validate the simulation model using the actual data.



(a)



(b)

Fig. 1 (a) Sidoarjo Porong roadway and surrounding areas; (b) Structure of Sidoarjo Porong roadway, direction: from Surabaya to Malang.

In this work, the actual data of the micro traffic flow is used; it is from the survey results of traffic flow on the Sidoarjo Porong roadway. The micro traffic flow system used is a combination of [4], [1], and [5]. Comparison of the fundamental diagram between the actual data and the simulation results is conducted. Time-space diagram and the evacuation time of the vehicles evacuation is also found in the simulation results based on the actual data.

2. Conditions of Sidoarjo Porong Roadway

Sidoarjo Porong roadway and surrounding areas are shown in Fig. 1(a). The straight line (blue color) in the middle part of the map is location of Sidoarjo Porong roadway. There is center of hot mudflow (the gray color) very close to this road. The road has two directional, from Surabaya to Malang and from Malang to Surabaya. In this work, we investigate one directional, i.e. from Surabaya to Malang; this part is adjacent to the center of mudflow. Visualization of this part is shown in Fig. 1(b) in which there are two lanes formally.

In the context that mud overflows into the road, we assume that it comes from one end of the road and has the same direction as the vehicles direction. In another sense, when we see in Fig. 1(b), we can say that mud will flow from left to right in accordance with the vehicles movement.

Survey of the traffic data on Sidoarjo Porong roadway was conducted. Survey was performed for the traffic by the direction from Surabaya to Malang (unidirectional). Road length for the traffic survey is 3.5 km (3500 m) start from point A to point B (Fig 1(a)). Our assumption is each car occupies about 7m of place, which is thus the length of one site. Some of samples the traffic data from the survey represent the mean speed $\bar{v}$ for different vehicles densities (low, intermediate, and high) are presented in Table 1. We can also see the conversion of mean speed for the simulation data. The low vehicles density; the intermediate one; and the high one used in the traffic data, are consecutively 0.2, 0.5, and 0.8.

Table 1: Conversion of real data to simulation data, for mean speed.

Density	Real data	Simulation
	Mean speed [km/hr]	Mean speed [site/time-step]
Low (0,2)	50	1.98
Intermediate (0,5)	37	1.47
High (0,8)	13	0.52

3. The Proposed Model

We propose the driver behavior parameters, agent drivers and diligent ones, and combine them into the car-following part of the micro traffic flow based on [4], [1], and [5]. The characteristics of agent drivers and diligent ones are explained in the section one. We can summarize that the agent drivers and the diligent ones have the ability to expand their chance increasing their speed in accordance with the information they get from the surrounding environment. Their ability can be reflected by the addition of the speed parameter on those, for each agent driver is $c' = [0 : v_{\max}]$ while for each diligent one is

$c = [0 : \min(\bar{v}, v)]$. These parameters have the sense that for an agent driver can expand the chance to increase the speed start from zero to maximum speed $v_{\max}$, while for a diligent driver is start from zero to minimum value between mean speed $\bar{v}$ and current speed *v*. With regard to the addition of the speed parameters, the velocity of an agent driver and a diligent one are respectively defined by the equations $v'_{i,j,t} = v_{i,j}(t) + [0 : v_{\max}]$ and $v_{i,j,t} = v_{i,j}(t) + [0 : \min(\bar{v}, v)]$. $v_{i,j}(t)$ is the velocity of the *ith* lane-*jth* site car by the time of *t*. $v'_{i,j,t}$ and $v_{i,j,t}$ are consecutive the velocity of an agent driver and a diligent one by the time *t* in the position *ith* lane-*jth* site.

In the model, the road consists of two lanes (Fig. 1(b)) and each lane is comprised of *L* sites of equal size. Each site can either be occupied by a vehicle or it can be empty. The number of agent drivers *Ag* is determined by the integer value, while diligent drivers are determined by using probability *dd*. The velocity for each vehicle is a single value between zero and $v_{\max}$. The initial velocity for each vehicle is determined by using normal random in which mean speed $\bar{v}$ and standard deviation *sd* as parameters inserted in the system. The total number of vehicles on the road is determined by the initial conditions using probability of vehicle density *k*, and with open boundary conditions. Due to the fact that the vehicles evacuation must be performed in the best way to minimize evacuation time *T*, the specific rules of the Nagel-Schreckenberg traffic cellular automata (NaSch) [2] is modified in the following for the car-following model. At each discrete time step $t \to t+1$, all the vehicles simultaneously update their states according to four consecutive steps:

1) Acceleration: if $v_{i,j}(t) < v_{\max}$ and $gs_{i,j}(t) > v_{i,j}(t) + 1$, $v_{i,j}(t+1) \to v_{i,j}(t) + 1$. $gs_{(i,j)}(t)$ is the distance between the *ith* lane-*jth* site car and the next car ahead.
2) Braking: if $gs_{i,j}(t) \le v_{i,j}(t)$, $v_{i,j}(t+1) \to gs_{i,j}(t) - 1$
3) Randomization: with probability *h* and random number $\xi(t)$, if $\xi(t) < h$; $v_{i,j}(t+1) \to v_{i,j}(t) - 1$
4) Vehicle movement: in accordance with the proposed parameters in the car-following part, agent drivers and diligent ones; vehicle movement is divided into three kinds,
   (*a*) $x_{i,j}(t+1) \to x_{i,j}(t) + v_{i,j}(t+1) + [0 : v_{\max}]$ for an agent driver,
   (*b*) $x_{i,j}(t+1) \to x_{i,j}(t) + v_{i,j}(t+1) + [0 : \min(\bar{v}, v)]$ for a diligent driver,
   (*c*) $x_{i,j}(t+1) \to x_{i,j}(t) + v_{i,j}(t+1)$ for an usual driver.

$x_{i,j}(t)$ is the position of the *ith* lane-*jth* site vehicle by the time *t*.

By referring [3], the modified lane-changing model is conducted by the following two rules consecutively executed at each time step: (*i*) the lane-changing model, exchanging vehicles between laterally adjacent lanes. By using two lanes; probability of lane-changing *lc*; and integer value $a = [0 : v]$, the rules are: if $gs_{i=1,j}(t) < v_{i=1,j}(t)$ and $x_{i=2,j,j+v}(t) = 0$, $x_{i=2,j+a}(t+1) \to x_{i=1,j}(t)$; and if $gs_{i=2,j}(t) < v_{i=2,j}(t)$ and $x_{i=1,j,j+v}(t) = 0$, $x_{i=1,j+a}(t+1) \to x_{i=2,j}(t)$. (*ii*) vehicle movement, all the vehicles are moved forward by applying three kinds of the vehicle movement in the step 4.

The lane-changing model describes that if in a lane, a driver is not possible to move his car forward (there is a car ahead) and he sees the empty sites in the other lane with the number of sites up to the speed *v* then he drives his car into the aforementioned lane. When a car is on a new lane, it has a speed less than or equal to the current speed *v*. It implies a deceleration that experienced by a car when it is moving to the other lane.

4. Simulation Results

In the simulation, the time is discrete and each lane of the road is divided into *L* sites of equal size. Regarding with the real situation on Sidoarjo Porong roadway, the road in a situation of evacuation has the distance 3500 m; it is as a road length *L*. In this work, *L* is assumed to be 500; the length of one site is set to 7 m. By referring to [2], one time step approximately corresponds to 1 second in real time. The initial speed for each vehicle is determined by using normal random with the value of parameters ($\bar{v}$ and *sd*) is depends on the vehicle density (probability of vehicle density *k*). In accordance with the real traffic data of the survey, the mean speed $\bar{v}$ (see Table 1) for the low vehicles density; the intermediate one; and the high one are rounded into 2, 1.5, and 1, successively. Standard deviation *sd* used in every kind of the vehicles density is 1. The following section, we show the fundamental diagram for the real traffic data and compare it with the fundamental diagram from the simulation results. Then, based on the real data, the time-space diagram is described, followed by the evacuation time of the vehicles evacuation for the proposed model.

4.1 Fundamental Diagram

There exists a unique relation between three of the macroscopic traffic flow characteristics, density k; flow q; and mean speed $\overline{v}$ [16-20]. The relation is expressed in the following equation: $q = k\overline{v}$. This relation is called the fundamental relation of traffic flow theory. In its original form, the fundamental diagram represents an equilibrium relation between q and k, denoted by $q(k)$. But note that, because of the fundamental relation of traffic flow theory, is it equally justified to talk about the $v(k)$ fundamental diagrams. Due to this equilibrium property, the traffic states (i.e., the density, flow, and mean speed) can be thought of as 'moving' over the fundamental diagrams' curves.

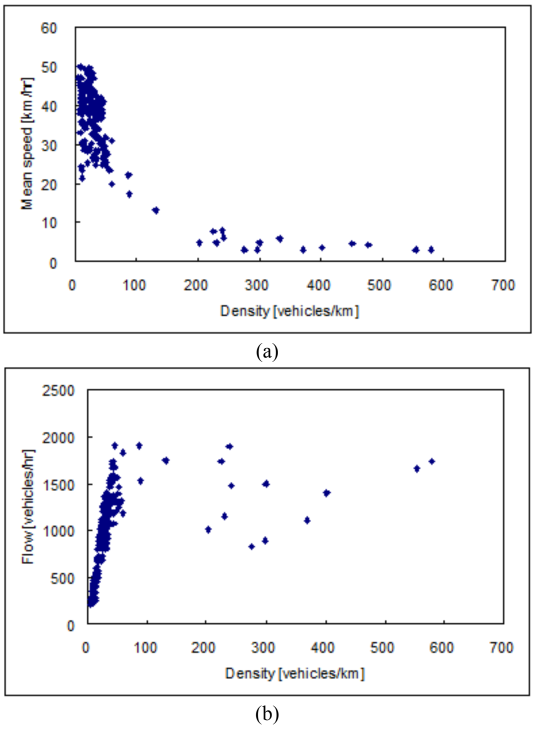


Fig. 2 Scatter plots of the relations between traffic flow characteristics as measured by the survey located at the Sidoarjo Porong roadway. The measured flows were converted into densities, the mean speed remained unchanged. (a) scatter plots of a (k- $\overline{V}$) diagram; (b) scatter plots of a (k-q) diagram.

We provide two scatter plots of fundamental diagram in Fig. 2. The shown data was obtained by means of a survey located at the Sidoarjo Porong roadway. Because of the nature of this data, we only obtained flows and mean speeds. The density is calculated from the fundamental relation of traffic flow theory. We construct scatter plots of the density, mean speed, and flow (a (k- $\overline{V}$) diagram and a (k-q) diagram). In free-flow traffic, interactions between vehicles are rare, and their small local disturbances have no significant effects on the traffic stream [16]. As a result, all points are somewhat densely concentrated along a line, representing the free-flow speed, in all two diagrams.

We present the fundamental diagram of our proposed model in Fig. 3. The specification of system that is used as stated above, road length L = 500 sites, probability of lane-changing lc = 0.4. For scatter plots of (k-q) diagram, it can be seen that the position of the maximum at about k = 0.5.

Using (k-q) diagram, we compare the position of the maximum between our model and the traffic measurements (survey results). From (k-q) diagram in the traffic measurements, the maximum value is found at about k = (86 vehicles per kilometre) = (0.602 vehicles/7 m). It is by a factor of about 1.2 higher than the position of the maximum in the scatter plots for our model. Similarly, we compare both of them (our model and traffic measurements) based on flow rate. From the traffic measurements (survey results), flow rate was found at about (1910 vehicles per hour) = (0.53 vehicles per second). As our maximum of the flow is only 0.41 vehicles per time step, our model time step should correspond to 0.41/0.53 ≈ 0.77 seconds, thus being by a factor of about 1.2 lower from the value presented above.

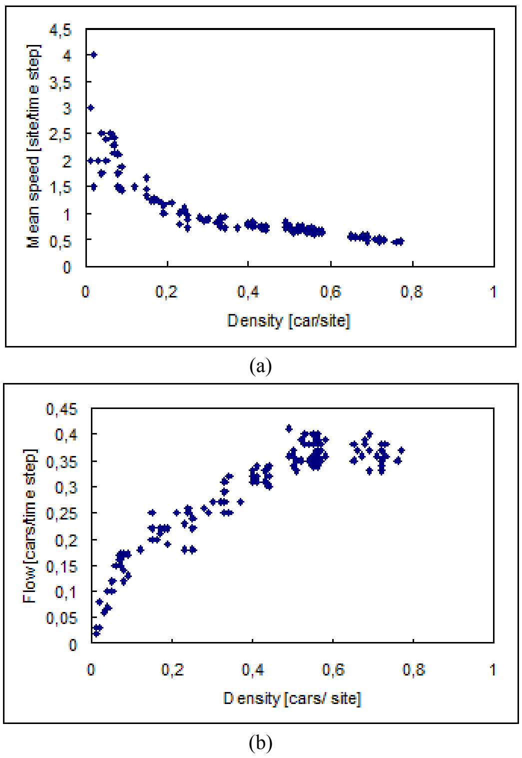
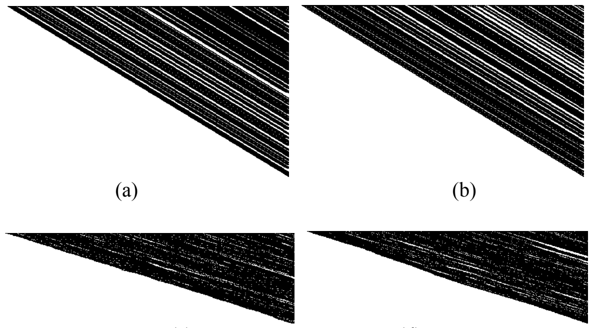


Fig. 3 Scatter plots of the relations between traffic flow characteristics. (a) scatter plots of a (k- $\overline{V}$) diagram; (b) scatter plots of a (k-q) diagram

4.2 Times-Space Diagram

In the time-space diagram, horizontal axis shows the space and vertical one is the time. All vehicles move from left to right. Each new line shows the traffic line after one further complete velocity-update and just before the vehicle motion. The time axis shows the evacuation time, its value increases from up to bottom.



(a) (b) (c) (d)

Fig. 4 Time-space diagram of the traffic referring to the realistic traffic on Sidoarjo Porong roadway, *k* is set to be 5 vehicles/site, *lc* = 0.8, mean speed $\overline{V}$ = 1.5, and *sd* = 1. (a) NaSch model for the 1st lane; (b) NaSch model for the 2nd lane; (c) our model for the 1st lane; (d) our model for the 2nd lane. Our model using *dd* = 0.8 and *Ag* = 5.

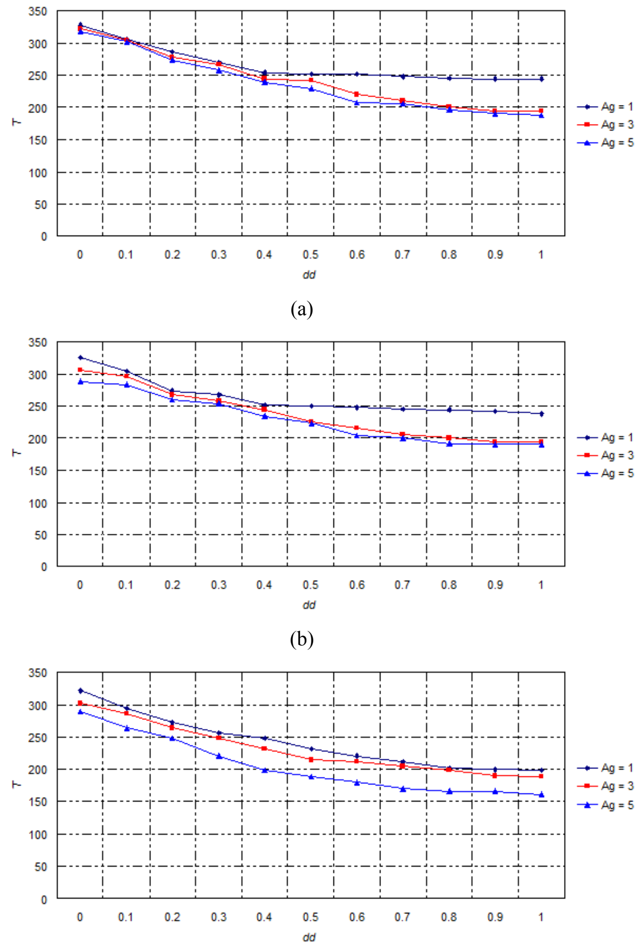
In Fig. 4(a) and 4(b), the formation of congestion waves leads to dense, compact jams containing a very solid vehicles running vine. Vehicles strive to decelerate smoothly, but are allowed to accelerate instantaneously when exiting jams fronts. In Fig. 4(c) and 4(d), the stable flow of vehicles occurs surrounding the dense. The evolution of the system dynamics qualitatively looks the same in both diagrams: the system is littered with mini-jams. As can be seen, for the intermediate density, the jams in our model contain moving vehicles.
The evacuation time for the NaSch model is found at 501, whereas for our model at 277. The effectiveness of our model compared by NaSch model is 45 %. We can say that the effect of agent drivers and diligent ones is almost double when the percentage ratio of diligent driver is 0.8 and the number of agent driver is 5.

4.3 Evacuation Time

In this section, based on the traffic measurements (survey results), we present the evacuation time *T* in various *Ag*, for unequal vehicle densities *k*. The mean speed $\overline{V}$ is found at about 2, 1.5, and 1, successively for the low vehicle density, the intermediate one, and the high one.

(i) The Low Vehicle Density

For the low vehicle density, *k* = 0.2; parameters $\overline{V}$ and *sd* for the initial velocity of each vehicle are 2 and 1, respectively. In Fig. 5(a), for *lc* = 0.3; and *Ag* = 1, 3, and 5; we obtain that with the increase of *dd* from 0 to 100 (%), *T* decreases for either *Ag* = 1, 3 or 5. This condition is also experienced for *lc* = 0.5; and *Ag* = 1, 3, and 5; when *dd* increases, we find *T* decreases (Fig. 5(b)). In Fig. 5(c), for *lc* = 0.8; and *Ag* = 1, 3, and 5; we obtain *T* decreases as *dd* increases. It is also found that with the increase of *Ag*, *T* decreases for each the same value of *dd*, this condition happens in every value of *dd*.

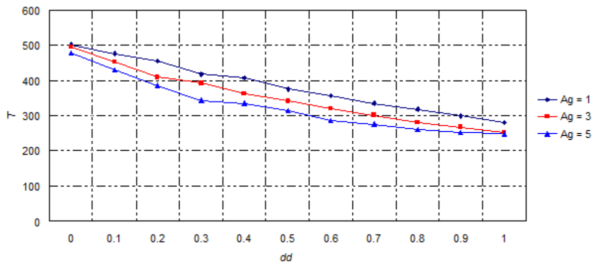


(a) (b) (c)

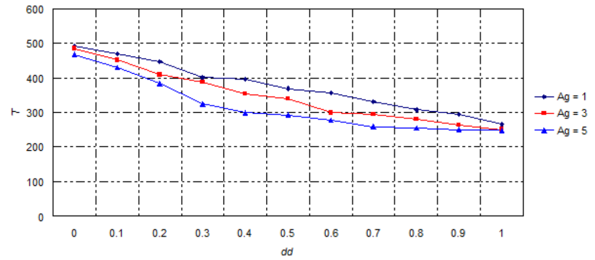
Fig. 5 *T* vs. *dd* for different *lc* at (a) *lc* = 0.3, (b) *lc* = 0.5, (c) *lc* = 0.8; *k* = 0.2.

(ii) The Intermediate Vehicle Density

For the intermediate vehicle density, *k* = 0.5; parameters $\overline{V}$ and *sd* for the initial velocity of each vehicle are 1.5 and 1, respectively. In Fig. 6(a), for *lc* = 0.3; and *Ag* = 1, 3, and 5; we obtain that with the increase of *dd* from 0 to 100 (%), *T* decreases for either *Ag* = 1, 3 or 5. This condition is also experienced for *lc* = 0.5; and *Ag* = 1, 3, and 5; when *dd* increases, we find *T* decreases (Fig. 6(b)). In Fig. 6(c), for *lc* = 0.8; and *Ag* = 1, 3, and 5; we obtain *T* decreases as *dd* increases. It is also found that with the increase of *Ag*, *T* decreases for each the same value of *dd*, this condition happens in every value of *dd*.



(a)



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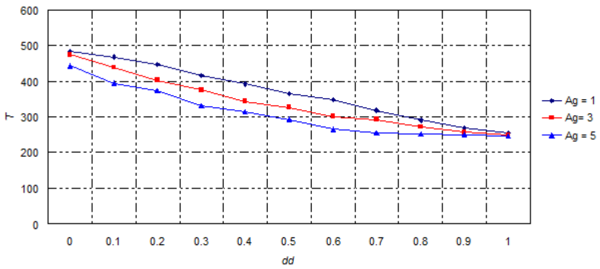
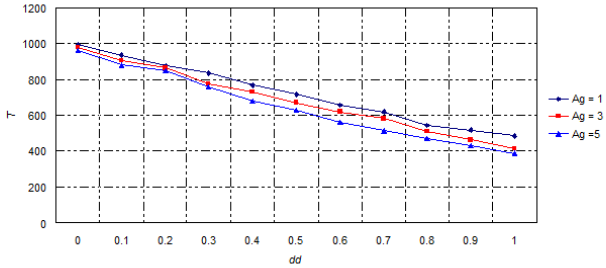


(c)

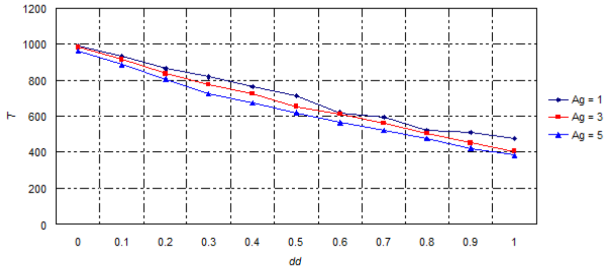
Fig. 6 *T* vs. *dd* for different *lc* at (a) *lc* = 0.3, (b) *lc* = 0.5, (c) *lc* = 0.8; *k* = 0.5.

(iii) The High Vehicle Density

For the high vehicle density, *k* = 0.8; parameters $\overline{v}$ = 1 and *sd* =1 for the initial velocity of each vehicle. In Fig. 7(a), for *lc* = 0.3; and *Ag* = 1, 3, and 5; we obtain that with the increase of *dd* from 0 to 100 (%), *T* decreases for either *Ag* = 1, 3 or 5. This condition is also experienced for *lc* = 0.5; and *Ag* = 1, 3, and 5; when *dd* increases, we find *T* decreases (Fig. 7(b)). In Fig. 7(c), for *lc* = 0.8; and *Ag* = 1, 3, and 5; we obtain *T* decreases as *dd* increases. It is also found that with the increase of *Ag*, *T* decreases for each the same value of *dd*, this condition happens in every value of *dd*.



(a)



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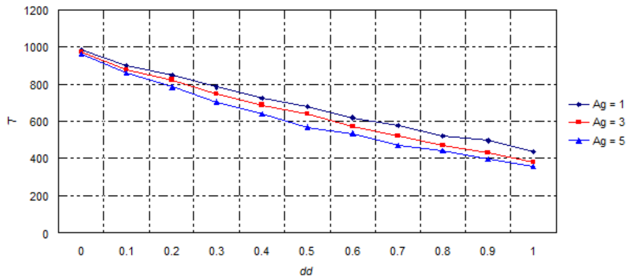

(c)

Fig. 7 *T* vs. *dd* for different *lc* at (a) *lc* = 0.3, (b) *lc* = 0.5, (c) *lc* = 0.8; *k* = 0.8.

5. Conclusion

Referring to the NaSch model, the additional driving behaviors are inserted into the car-following part of micro traffic. Comparison of the fundamental diagram between the actual data and the simulation results; the effect of agent drivers and diligent ones; and the evacuation time of the vehicles evacuation, are investigated.

Based on (*k*-*q*) diagram, the position of the maximum in the traffic measurements (survey results) is located at about 1.2 higher than the position of the maximum in the scatter plots for our model. We also find that our maximum of the flow is 1.2 lower than the maximum value presented by the traffic measurements (survey results). Regarding to the time-space diagram, the effect of agent drivers and diligent ones is obtained, it is almost double when the percentage ratio of diligent driver is 0.8 and the number of agent driver is 5.

The simulation results also find the evacuation time of vehicles evacuation by the condition that with the increase of diligent drivers, evacuation time decreases either in the low vehicle density, in the intermediate one, or in the high one. In these relations are also shown that with the increase of the number of agent drivers, the evacuation time decreases for each the same value of diligent drivers.

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